Comment:

Thank you for clarifying the issues I raised in my first review. There is just one remaining issue, where I think further discussion would be useful. That is the question of the stray light contribution in the Brewer instruments. I still wonder if out-of-band stray light scattered from longer wavelengths could contribute to a larger error in erythemally-weighted UV than estimated by the authors. They quote a stray light rejection of 10(-3) or 10(-4). But my understanding is that figure applies to the stray light from a monochromatic source measured several bandpasses from the centre wavelength. In the case of spectral UV measurements of sunlight, the situation is much worse because, rather than a single line, there is a continuum of longer wavelengths with irradiances that are orders of magnitude larger than those expected in the wavelength region of interest (mainly 300 to 310 nm for erythemally weighted UV). That is why double monochromators are preferred for the purposes of monitoring solar UV irradiance incident at Earth's surface. It is difficult to demonstrate the problem (or lack of it) using model calculations because in the wavelength region of interest, uncertainties in the value of ozone input to the model could have a similar spectral effect. Perhaps the best way to resolve the issue would be to compare the output of single-monochromator and double-monochromator versions of the Brewer instruments while making simultaneous measurements at the same site. Although I'm not aware of a publication that shows this, I'd be surprised if the study had not been undertaken during the development of the double version. It would be particularly interesting to see how the measured spectra diverge from each other at shorter wavelengths for the ozone amounts and relatively large solar zenith angles that apply in this case. Hopefully the addition of a citation will suffice. If not, perhaps another paper is needed.

Response:

Single-monochromator Brewer spectrophotometers are equipped with a Nickelsulfate ($NiSO_4$) filter that is sandwiched between two UG-11 windows. The composite filter has a transmission of about 80% between 250 and 300 nm, 70% at 310 nm, 40% at 340 nm, and 15% at 330 nm. The filter is opaque for wavelengths larger than 350 nm. The steep cut-off of the filter towards longer wavelengths is one of the reasons why single-monochromator MKII Brewer instruments only report spectral irradiance up to 325 nm. Visible radiation does not enter the monochromator because of the use of the filter and cannot contribute to stray light. Hence, stray light is less of a problem for single-Brewer systems compared to single-monochromator devices that are also sensitive to the visible spectral range.

Measurements of a double- and single-monochromator Brewer instrument have been compared by Bais et al. (1996) using measurements performed at Thessaloniki, Greece. Figure 1 of that paper shows that measurements of the single-Brewer are affected by stray light below 300 nm. According to the paper, wavelengths below 300 nm contribute only 6% to the erythemal dose rate for a solar zenith angle (SZA) of 20°. At SZA = 65°, the contribution is only 0.5%. As the Sun sets, stray light errors at a fixed wavelength below 300 nm increase, however, the center of the erythemally-weighted spectrum moves to longer wavelengths such that even relatively large stray light errors at short wavelengths contribute only little to the overall erythemal dose rate. Bais et al. (1996) conclude that "the erythemal dose rate calculated by the two Brewer instruments [i.e., one single and one double system] should not vary by more than about 1%."

Bais et al. (1996) only considered measurements with SZAs between 20° and 65° and total ozone of about 300 DU. In the following we use model calculation to determine whether stray light related errors in single Brewer UVI measurements become significant for the large SZAs observed during March in the Arctic.

Model spectra were calculated with the radiative transfer model UVSPEC/libRadtran for SZAs between 1° and 90°, and ozone columns of 230 DU (lower limit for the Arctic) and 550 nm (upper limit). Additional spectra were calculated for the conditions described by Bais et al. (1996) (SZA = 20°, 50°, 64°; ozone = 300 DU). All spectra were weighted with the CIE action spectrum for erythema and compare to similar results obtained with spectra $E_S(\lambda)$ that included a stray light component:

$$E_S(\lambda) = E(\lambda) + \alpha \times \int E(\lambda') * F(\lambda') d\lambda', \qquad (1)$$

where

$E(\lambda)$ is the spectral global irradiance calculated with the model,

$E_S(\lambda)$ is the spectral global irradiance affected by stray light,

$F(\lambda')$ is the spectral transmission of the $NiSO_4$ filter, and

α is the stray light contribution factor.

The parameterization assumes that stray light is a wavelength-independent, constant value. The factor α was set to 10^{-5}. By choosing this value, simulated spectra for SZA = 20°, 50°, 64° become similar to the single-Brewer measurements shown in Figure 1 of Bais et al. (1996). (In other words, the factor α is used to tweak the simulation such that the results match the measurements by Bais et al. (1996)).

Figure A shows a comparison of $E(\lambda)$ and $E_S(\lambda)$ for the conditions discussed by Bais et al. (1996). The simulated results are very similar to the measurements by Bais et al. (1996) at all SZAs, indicating that the model-approach can be used with confidence to estimate the effect of stray light on measurements of erythemal dose rates also at larger SZAs. Of note, Figure A also indicates that the peak of the erythemally weighted irradiance is more than two orders of magnitude larger than the stray light level at all SZAs.

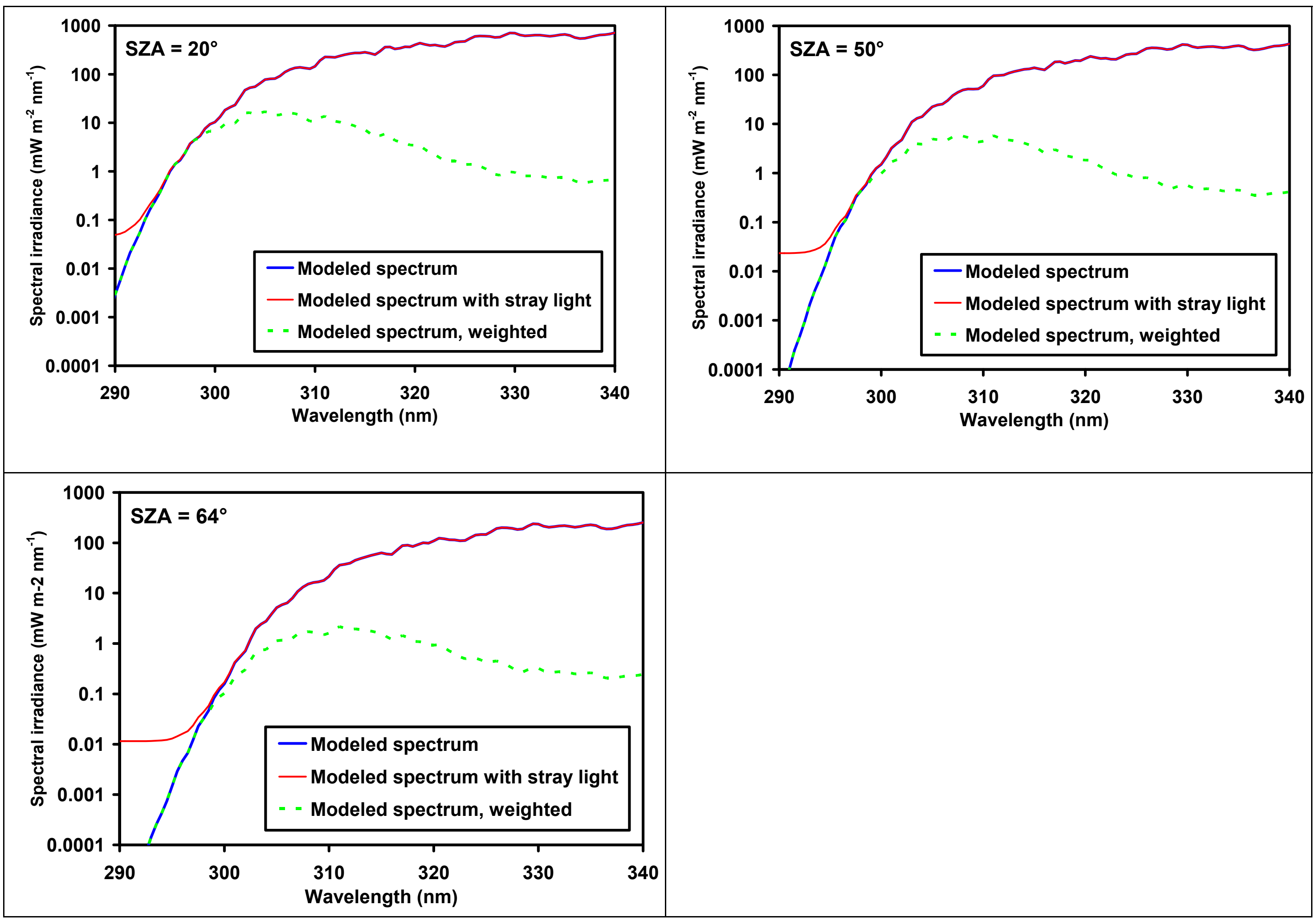

Figure A: Comparison of model spectra (blue) for SZA = 20° (top left), 50° (top right), and 64° (bottom left) with model spectra that contain a stray light contribution according to Eq. (1) (red). The dotted green lines indicate erythemally-weighted model spectra. The simulated data match the results shown in Figure 1 of Bais et al. (1996).

Model spectra $E(\lambda)$ and $E_S(\lambda)$ for all SZAs were weighted with the erythemal action spectrum and the UV Index was calculated. The difference in the UV Index determined from the stray-light affected spectra ($E_S(\lambda)$) and the unaffected spectra ($E(\lambda)$) is shown in Figure B. The difference between the two datasets is smaller than 0.8% at all SZAs, indicating that systematic errors due to stray light have only a very small effect on single-Brewer UVI measurements.

We note that all Brewer measurements used for our paper were stray-light corrected by subtracting the average spectral irradiance measured between 290 and 292.5 nm from the whole spectrum. Hence, the stray light effect on UVI measurements is in fact smaller than indicated in Figure B.

The following will be added to the manuscript:
"Measurements of single-monochromator Brewer instruments are affected by stray light. Bais et al. (1996) have shown that systematic errors in Brewer UVI data due to stray light are smaller than 1% for SZAs between 20° and 65°. Using model calculations, we confirmed that stray light errors are also below 1% for SZAs between 65° and 90° and ozone columns between 230 and 550 DU."

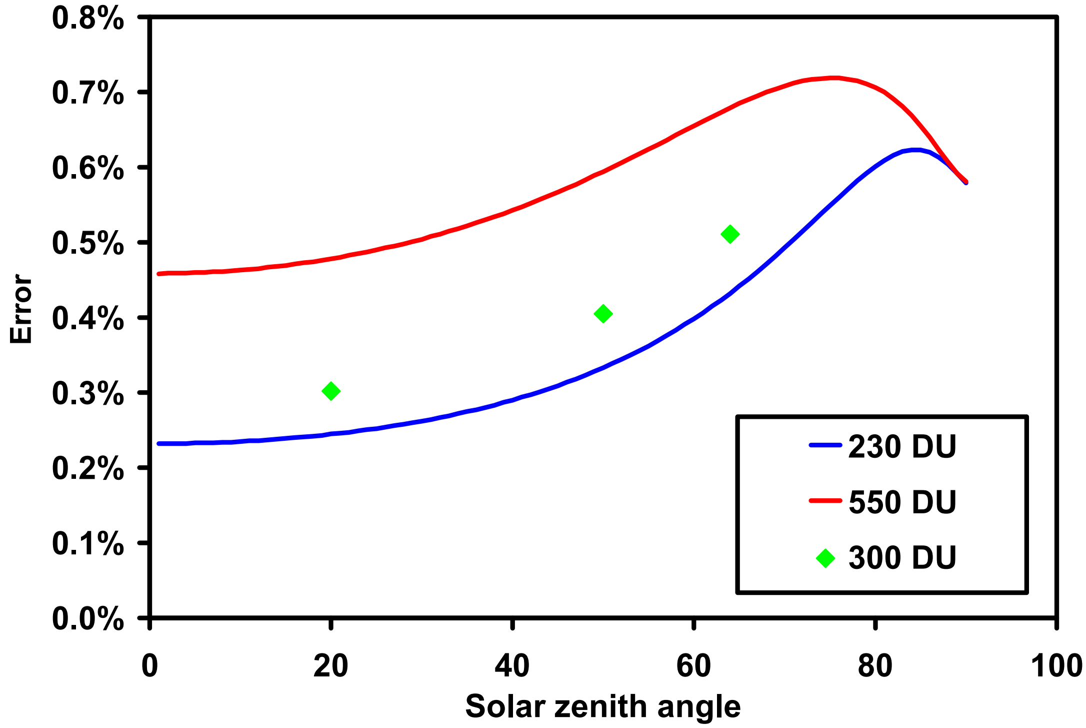

Figure B: Simulated systematic errors in UV Index data derived from single-Brewer measurements because of stray light. The dataset indicated by green diamonds is based on the spectra shown in Figure A.

Reference:

Bais, A.F., Zerefos, C. S., and McElroy, C. T.: Solar UVB measurements with the double- and single-monochromator Brewer ozone spectrometers, Geophys. Res. Lett., 23(8), 833-836, 1996.